A Deterministic Quantum-Informational Hash Descriptor for Multi-Scale Physical Systems

A Reproducible Physical-Informational Identity Spanning Microscopic, Macroscopic, Astronomical, and Biological Scales

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Primary classification: gr-qc (General Relativity and Quantum Cosmology). Cross-list: quant-ph, physics.data-an, cs.CR.

Scope and Intellectual-Property Notice

This preprint communicates the conceptual architecture, design rationale, positioning, and applications of the descriptor. The operational core — the explicit composition map, the closed-form continuous descriptor and its coefficients, the normalization and calibration rules, the canonical serialization scheme, and the specific cryptographic instantiation — is the subject of an intellectual-property filing (WIPO) and is deliberately withheld. The relations shown here are presented only at the level of named components and symbolic roles; they are insufficient, by design, to reconstruct, re-derive, reverse-engineer, or re-implement the protected pipeline by analytical, numerical, or automated (including AI-assisted) means. Requests for evaluation under appropriate confidentiality arrangements may be directed to the author.

Companion note. *This descriptor is the informational-invariant component of the author's Unified Variational Principle (UVP); the two documents are complementary. Within the UVP, the descriptor realizes the holographic information-preservation role; here it is developed as a stand-alone, reproducible identity layer for physical and informational systems.*

Abstract

We present the conceptual architecture of a **deterministic quantum-informational hash descriptor** — a hybrid physical-informational identifier that maps the state of a system, at a given time, into a reproducible continuous descriptor and a stable discrete identity. The descriptor integrates seven roles into a single deterministic object: a normalized state representation, an effective observable summary, an entropy measure, a physical energy-scale anchor, a deterministic temporal index, a causal-consistency descriptor, and structured provenance metadata. Unlike quantum fingerprinting[1], which compresses an abstract input string into a quantum state, and unlike classical provenance and workflow identifiers[6], which operate on files and execution records, the present descriptor is constructed directly from physically meaningful observables — including the von Neumann entropy of the state[2] and a mass-energy scale anchor[3] — and is designed to be applicable across more than thirty orders of magnitude, from microscopic quantum systems to galaxies and cosmic-scale structures. The framework yields reproducible cross-platform identity, kinematic tracking, and provenance-grade traceability. This document states the architecture, its positioning against existing model families, and its applications, while withholding the operational core under intellectual-property protection.

1. Introduction

Modern science increasingly depends on reproducible identification and traceability of system states across heterogeneous platforms: simulations, laboratory measurements, observational catalogs, and data-driven pipelines. Conventional cryptographic identifiers are purely syntactic — they certify that a byte string is unchanged, but say nothing about the physical meaning of the system they label. Conventional scientific provenance, in turn, is artifact-centered: it tracks files, code versions, and execution logs, but not the interpreted physical-informational configuration of the system itself.

This work introduces a descriptor that occupies the gap between these two worlds. It is neither a pure cryptographic primitive nor a pure provenance record. Instead, it is a **hybrid physical-informational identity**: a single deterministic object that simultaneously encodes what a system is (its state and effective observable), how disordered it is (its entropy), how large it is (its energy scale), when it is evaluated (its temporal index), whether the evaluation is causally admissible (its causal descriptor), and in what context it was produced (its provenance metadata).

Two design commitments distinguish the framework. First, *multi-scale universality*: the same architecture is intended to apply, without structural change, to microscopic quantum systems, macroscopic physical objects, astronomical bodies, and aggregated biological states. Second, *determinism*: identical inputs, under fixed and declared rules, must always yield the same identity, so that the descriptor can serve as a reproducible reference across independent implementations and observatories.

2. The Descriptor Architecture

At the highest level of description, the descriptor is a deterministic map from a structured tuple of system roles into a stable identity. Writing the system as *O* evaluated at time *t*, the architecture is summarized schematically as:

$$Identity(\,O\,;\,t\,) \;\leftarrow\; \mathcal{H}\,[\,state,\, observable,\, entropy,\, energy,\, time,\, causality,\, provenance\,]$$

The symbol $\mathcal{H}$ denotes the protected composition-and-serialization map that defines the framework; its explicit form, coefficients, and instantiation are withheld. The bracketed entries are *roles*, not formulas. Each role is summarized below at the level of its purpose and observable meaning only.

2.1 The seven component roles

- **State representation.** A normalized representation of the system configuration that satisfies the standard validity conditions of a physical state. It is the structural foundation of the descriptor.
- **Effective observable summary.** A single scalar that summarizes the system's structure and dynamics through an effective operator appropriate to its class. The construction and calibration of this operator are withheld.
- **Entropy measure.** A measure of the informational disorder of the state, of von Neumann type for quantum states[2], with classical analogues for classical states. A normalized, bounded form is used internally; the reference scaling is withheld.
- **Energy-scale anchor.** A positive physical scale marker that anchors the descriptor to the magnitude of the system, in the spirit of mass-energy equivalence[3]. This is what allows a single framework to span many orders of magnitude.
- **Temporal index.** A deterministic, discrete label for the instant of evaluation, fixed by a declared time origin and rounding rule, so that repeated evaluations are reproducible.
- **Causal descriptor.** A bounded, deterministic code expressing whether the evaluated state, event, or lineage is causally admissible — the same causal-protection logic that appears as a constraint in the companion Unified Variational Principle[5].

- **Provenance metadata.** Structured contextual information — system class, scale class, protocol, version, source — standardized so the identity is uniquely attributable and reproducible, in the spirit of established provenance models[6].

2.2 From components to identity

The descriptor is produced in two conceptual stages. The components are first combined into a *continuous descriptor* that carries the physical scale and the informational disorder of the system in a compact analytic object. The continuous descriptor, together with the temporal, causal, and provenance roles, is then serialized under a fixed canonical scheme and committed to a *stable discrete identity* by a standardized cryptographic hash of the SHA-3 family[4]. The exact form of the continuous descriptor, its coefficients, the normalization and calibration rules, the canonical serialization, and the specific hash instantiation are part of the protected core and are not disclosed here.

$$components \rightarrow [\, continuous\ descriptor \,] \rightarrow canonical\ serialization \rightarrow stable\ identity$$

Two structural properties follow from this design and can be evaluated independently of the protected internals. **Determinism**: under fixed, declared rules, identical inputs always yield identical identities. **Sensitivity**: any change in the underlying state, scale, time, causal status, or context yields a different identity, which is precisely what makes the object useful for traceability.

3. Positioning Relative to Existing Model Families

The descriptor is best understood not as a competitor to any single mature category, but as an integrative bridge between three families that each address part of the problem. The table summarizes the comparison at the level of inputs, outputs, and relationship to the present framework.

Existing family	What it does / its limitation here	Relationship
Quantum fingerprinting / hashing	Compresses an abstract classical input into a compact quantum state for equality and communication tasks; not anchored to physical observables, scale, or provenance	Conceptual inspiration; not a direct equivalent [1]
Provenance & workflow identifiers	Tracks files, code, logs, and dataset manifests for reproducibility; lacks physical-state, entropy, and operator semantics	Highly compatible integration target [6]
Device / physical fingerprinting	Derives a signature from experimental or hardware statistics; specialized to device attestation rather than general multi-scale identity	Compatible in the provenance layer, but narrower
Present descriptor	Builds identity directly from state, observable, entropy, energy scale, time, causality, and provenance, across many scales	Novel integrative framework

The novelty does not lie in any single sub-component — entropy measures, energy scales, deterministic indexing, and cryptographic hashing are all established. It lies in the integration: the fusion of physically meaningful observables, entropy structure, deterministic temporal and causal labeling, and standardized provenance into one reproducible identity that spans physical, informational, and biological domains.

4. Multi-Scale Applicability and the Astronomical Case

Because the descriptor is anchored by a physical scale rather than by a fixed dimensionality, it is designed to apply across more than thirty orders of magnitude without structural change. A natural and demanding test case is **astronomical identity**: assigning a reproducible, cross-observatory identity to celestial objects and tracking their kinematic evolution over time.

In the astronomical specialization, each object's state, effective observable, entropy, mass-energy scale, atomic-time index, causal status, and catalog metadata are combined into the descriptor exactly as in the general architecture. Successive evaluations of the same object at different epochs yield a chain of identities, supporting reproducible tracking, provenance-grade catalog integrity, and synchronization across independent observatories. The same construction applies, in principle, to planets, stars, exoplanets, galaxies, black holes, nebulae, cosmic filaments, and dark-matter halos.

A biological specialization follows the same logic, restricted by design to *aggregated, non-sensitive descriptors* — tissue or sample-scale markers, heterogeneity-based entropy surrogates, protocol identifiers, and lineage-validity flags — rather than raw patient-level or genomic content. This restriction is a deliberate ethical and privacy commitment of the framework.

5. Applications

The descriptor adds a semantically richer identity layer wherever syntactic identifiers are too shallow and artifact-centered provenance is too narrow.

1. **Reproducible scientific identity.** A stable reference for system states across simulations, measurements, and re-analyses, complementing existing provenance chains.
2. **Cross-platform synchronization.** Independent observatories or laboratories can agree on the identity of a system without sharing raw data, only declared rules.
3. **Kinematic and temporal tracking.** Identity chains over successive epochs support reproducible tracking of evolving systems.
4. **Catalog and dataset integrity.** Multi-version datasets and reference catalogs gain a deterministic, tamper-evident state identity.
5. **Provenance-aware AI pipelines.** Hybrid pipelines can preserve not only file identity but system-state identity, improving auditability.

6. Discussion and Outlook

The descriptor converts a physical-informational state into a reproducible identity by separating cleanly between measured state structure, derived informational quantities, a physical scale anchor, deterministic indexing, and standardized serialization. Its strength is that this separation is explicit and class-adaptable while remaining deterministic within each class. Within the author's broader program, it supplies the information-preservation role of the Unified Variational Principle, giving the unified model a concrete, reproducible informational invariant.

The natural next steps are controlled disclosure of the operational core under confidentiality, reference implementations validated against declared rules, and empirical evaluation of determinism, sensitivity, and

cross-platform agreement in physical, astronomical, and aggregated-biological settings. Engagement is welcomed from the gravitational, quantum-information, scientific-provenance, and complex-systems communities.

Intellectual-Property Statement

The conceptual architecture described in this document is original to the author. The operational core — the explicit composition-and-serialization map, the continuous descriptor and its coefficients, the normalization and calibration rules, the canonical serialization scheme, and the specific cryptographic instantiation — is the subject of an intellectual-property filing (WIPO) and is withheld. Nothing in this preprint should be construed as a public disclosure sufficient to reconstruct, re-derive, reverse-engineer, or re-implement the protected pipeline. The author retains all rights to the operational content.

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